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Novel Ring Resonator-Based Optical Beamformer for Broadband Phased Array Receive Antennas

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***Abstract*—A squint-free, continuously tunable optical beamformer system for phased array receive antennas is proposed and experimentally demonstrated, which involves an integrated ring resonator-based optical beam forming network, filter-based optical SSB-SC modulation and balanced coherent detection.**

I. Introduction

Beam forming of a phased array antenna can be realized by processing the antenna signals through an optical beamformer circuit, with the advantages of compactness, small weight, low loss, frequency independence, high instantaneous bandwidth, and EMI immunity. Many conventional optical beamformers are either using optical phase shifters or switchable true time delay (TTD) arrays [1], [2], which have the disadvantages of beam squint for broadband signals and limited tuning resolution, respectively. Chirped fiber gratings (CFGs) can be used as an alternative, to offer both continuous tunability and TTD [3]. However, it requires bulky optical components and a tunable laser. In this paper a novel, CW-laser-compatible, squint-free, continuously tunable beamformer mechanism for a phased array receiver system is presented and experimentally demonstrated. The core of the beamformer is an integrated optical ring resonator (ORR)-based optical beam forming network (OBFN). The E/O and O/E conversions around the OBFN are performed by means of filter-based optical single-sideband suppressed-carrier (SSB-SC) modulation and balanced coherent optical detection, which provides advantages in optical chip complexity and system dynamic range [4]. The novel optical beamformer system is explained in Section II. In Section III some experimental results are presented to demonstrate the concepts. Conclusions are given in Section IV.

II. Novel Optical Beamformer System

A. System setup

The core of the presented optical beamformer system consists of an ORR-based OBFN for tunable TTD generation, an optical sideband filter (OSBF) for SSB-SC modulation, and an optical carrier reinsertion circuit for balanced coherent detection. The complete system setup is shown in Fig. 1. ORRs are capable of providing continuously tunable TTD over a certain optical bandwidth and therefore can be used as the delay elements in an OBFN. The principles of ORR-based OBFNs have been explained in [5], [6].

B. Advantages of using optical filter-based SSB-SC modulation and balanced coherent detection

The presented system uses SSB-SC modulation instead of straightforward DSB modulation, in order to reduce the optical signal bandwidth after modulation. The resulting optical bandwidth from SSB-SC modulation equals merely the RF bandwidth, which significantly reduces the OBFN complexity, namely the required number of ORRs to achieve a certain TTD bandwidth [5], [6]. For easy implementation of the SSB-SC modulation, the configuration of MZMs and OSBFs is used [4]. Since both the OSBF and the OBFN are linear devices, their order can be reversed, so that the sideband filtering can be performed by placing only one common OSBF after the OBFN instead of one OSBF directly after each MZM, as shown in Fig. 1. For system integration, an OSBF has been built by combining an MZI and an ORR [7], which are the same building blocks as used in the OBFN. Optical SSB-SC modulation requires coherent optical detection. Therefore, the unmodulated optical carrier must be re-inserted before optical detection. Balanced detection is used instead of direct single-ended detection, because it enhances the dynamic range of the system [4], [8].

III. Realization and Measurements

Integrated optical chips, each containing an ORR-based OBFN, an OSBF, and an optical carrier reinsertion circuit, have been realized in the TriPleX waveguide technology of LioniX [9]. The waveguide layout of a chip with a 4×1 OBFN is shown in Fig. 2, where the four signal channels differ in the number of cascaded racetrack-shaped ORRs for different required TTDs. The measurements on a separate OBFN chip and an OSBF chip in TripleX technology have been presented previously in [6], [10]. Measurements on the novel optical beamformer system have been performed lately from RF to RF, to demonstrate the functionality

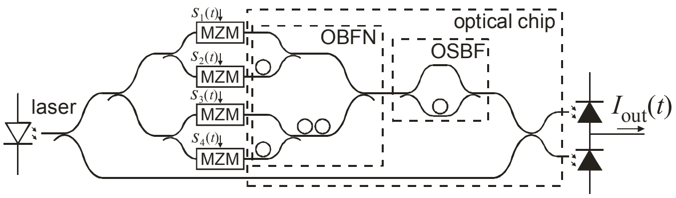

Fig. 1: Schematic of novel beamformer system

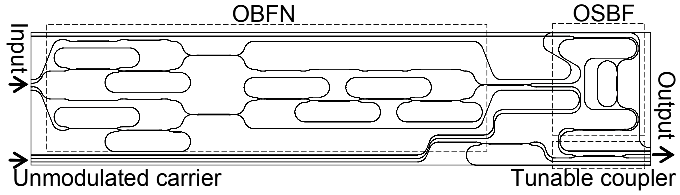

Fig. 2: Waveguide layout of an integrated beamformer chip

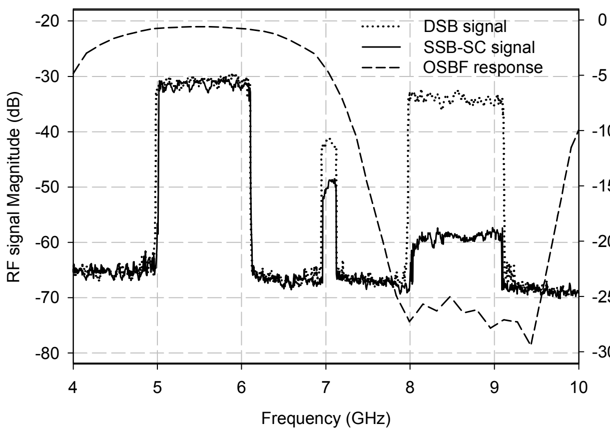

Fig. 3: Filter-based optical SSB-SC modulation

of the system. Sideband filtering and carrier suppression for RF frequencies from 1 to 2 GHz are shown in Fig. 3. For this measurement the optical heterodyning technique is used before optical detection, to shift the spectrum of the modulated optical signal down into the frequency range of the RF spectrum analyzer, by mixing the modulated light with CW light. The peak between two sidebands in Fig. 3 indicates the frequency difference between the two heterodyning optical carriers. It is shown that the magnitude of one sideband of the signal is 25 dB suppressed by the OSBF. When the OSBF is working properly, the ORRs of each signal channel of the OBFN can be tuned such that a flat group delay response covers the frequency range of the remaining sideband of the modulated optical signals. Three group delay responses of a signal channel on the optical beamformer chip are shown in the inset of Fig. 4, with the maximum value of 1.5 ns (45 cm delay distance in air). For simple demonstration of signal recovery by means of coherent optical detection, single-ended detection is performed after the combination of the delayed sideband and the unmodulated optical carrier. The recovered RF signals over the frequency range from 1 to 2 GHz are shown in Fig. 4 in terms of RF-to-RF phase responses, after the processing of optical SSB-SC modulation, channel group delay and coherent optical detection. The phase response for 0 ns group delay is regarded as zero phase response, and the other two phase responses show good match to the corresponding delay values.

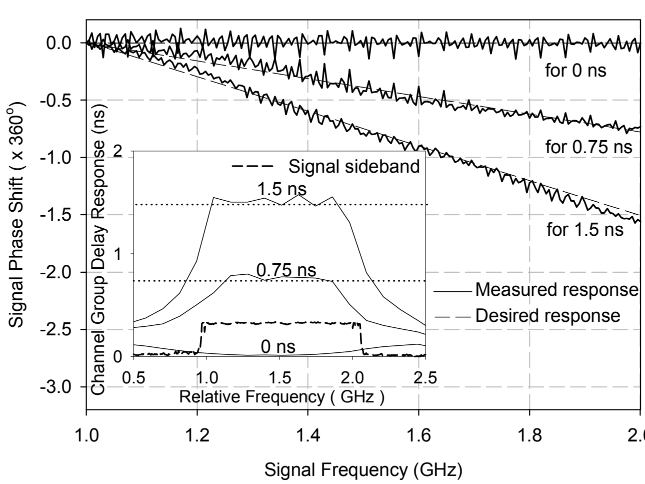

Fig. 4: Signal phase shift for different channel delays (inset)

Though not shown in the figure, the corresponding magnitude responses of the RF signal are flat over the signal band, but with larger loss for higher delay, because the optical loss increases with delay value [6], [9]. Besides, the ripples in the results are mainly due to the optical phase fluctuation at the optical carrier reinsertion, which comes from the slight fluctuation in the position and temperature of the optical fibers before the chip. In the future implementation this will not be a problem because the full beamformer will be integrated to a single chip including laser splitter and modulators.

IV. CONCLUSIONS

A novel squint-free, continuously tunable beamformer mechanism for phased array receiver systems has been presented. It is based on filter-based optical SSB-SC modulation, ORR-based OBFN, and optical balanced coherent detection. The system has been experimentally demonstrated by some measurements on optical sideband filtering, channel group delay responses, and RF-to-RF signal responses.

ACKNOWLEDGMENT

This work was part of the Broadband Photonic Beamformer project and the SMART project, both supported by the Dutch Ministry of Economic Affairs, SenterNovem project numbers IS052081 and IS053030, respectively. The SMART project is part of the Euripides project SMART.

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